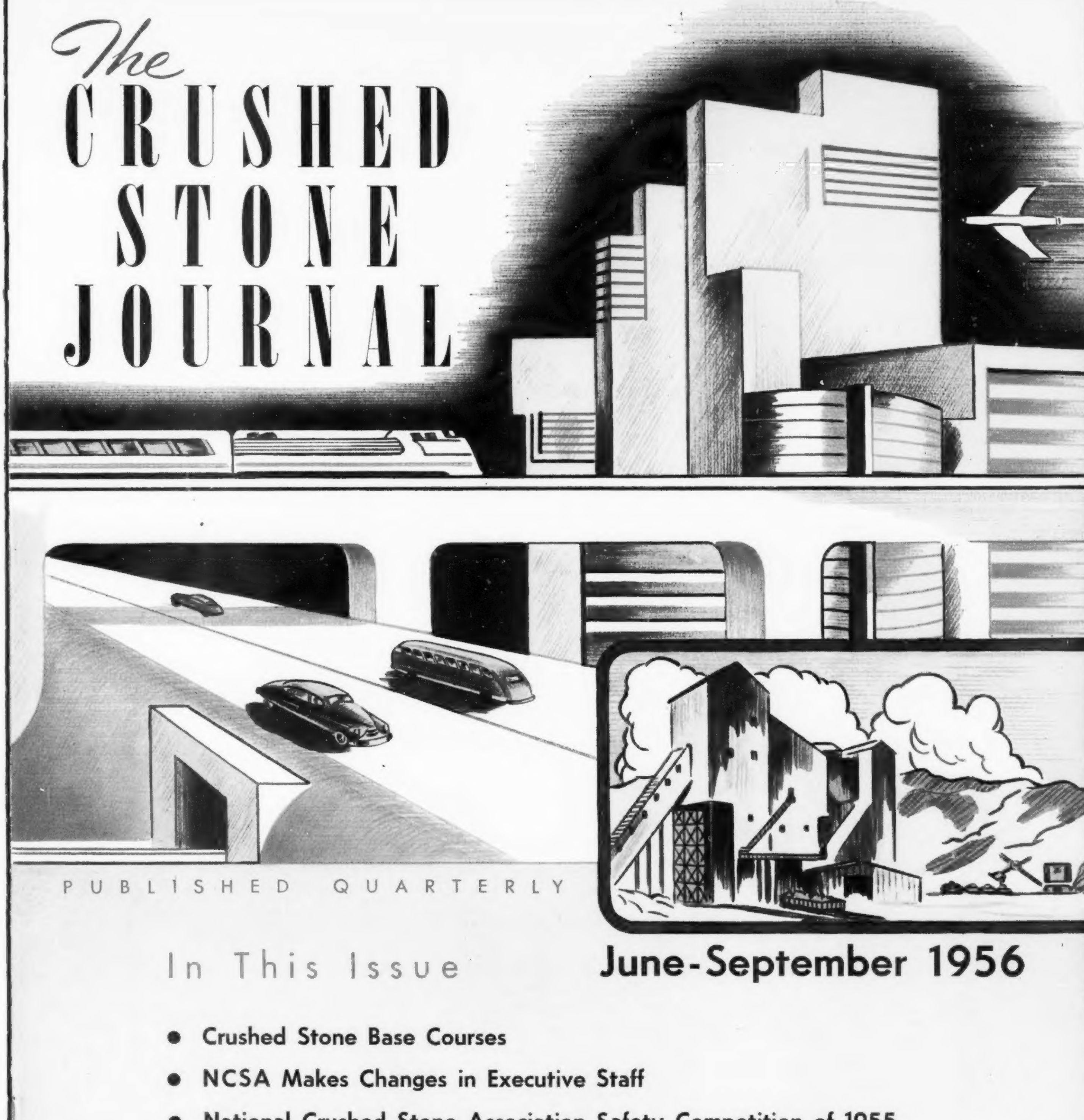
The CRUSHED STONE JOURNAL



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The Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

J. R. BOYD, Editor

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THE CRUSHED STONE JOURNAL

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Crushed Stone Base Courses[1]

By JOSEPH E. GRAY

Engineering Director
National Crushed Stone Association

THERE is little by way of theory to form a background for a paper on crushed stone base courses. Several theories have been advanced for the design of flexible pavements, but the underlying principle of these design procedures is that the total thickness must be such that the maximum wheel load is reduced or distributed to the subgrade so that the unit pressure on it is within allowable limits. A flexible pavement design is a design of a layered system with each layer stronger than the one under it. Thus, for an arterial highway, a flexible pavement might consist of a 10 in. subbase of selected granular material, 8 in. crushed stone base, 3 in. penetration macadam, 2 in. binder, and 1 in. bituminous surfacing mix. While on the other hand, farm to market roads often are built of 6 in. crushed stone base and 1 in. oil mat. The subject under discussion in this layered system is the current practices and trends in the construction of the crushed stone base course.

There are two types of crushed stone base courses being built today; dry-bound or water-bound macadam and graded aggregate. Macadam base which may be either dry-bound or water-bound consists essentially of a course of large closely sized stone, often 3 1/2 to 1 1/2 in., which is placed on a prepared subgrade to a given thickness, shaped, compacted, then the voids are filled with stone screenings and the surface is finally watered and rolled. Graded aggregate base course consists essentially of crushed stone graded from about 1 1/2 in. down to and including the dust of fracture which is placed on the prepared subgrade to a given thickness and is compacted to maximum density after water has been added to bring the moisture content to the optimum.

Relative Evaluation of Macadam and Graded Aggregate Bases

It will be the purpose of this paper to review the quality and gradation requirements for the stone, to make an engineering and economic evaluation of these two types of bases, and to discuss the best construction practices.

Quality Requirements

Most specifications read to the effect that crushed stone for water-bound macadam should consist of hard, durable stone, free from an excess of flat and elongated, soft or disintegrated pieces, and should have a percentage of wear of not more than 50 in the Los Angeles abrasion test. In areas where the supply of hard stone is plentiful, the Los Angeles abrasion loss requirement is lowered to not over 35 per cent. A soundness requirement is usually in the specifications if the base may be subjected to frost action. The quality requirements for the screenings are usually that it must be produced from the same parent rock as the large stone.

The quality requirements of the stone for graded aggregate base are quite different from that of water-bound macadam. This type of base, for the most part, has been built in areas where stone quarries are not established. The quality requirements for the stone are very well described in the ASTM

[1] Presented before the Fifteenth Annual Convention, Southeastern Association of State Highway Officials, Roanoke, Virginia, September 7, 1956

Tentative Specification D 1241-55T, which states that the "Coarse aggregate shall have a percentage of wear, by the Los Angeles test, of not more than 50. Note.—A higher or lower percentage of wear may be specified by the engineer, depending upon the materials available for the work." It, therefore, appears that the actual specifications on the parent rock are wide open. Since the stone for this type of construction is graded down to and including the dust, it is essential that limitations be placed on the liquid limit and the plasticity index. In general, the liquid limit requirements are that it shall not be over 25 or 30 and the plasticity index is usually limited to not over 6. These latter limitations have been considered important and, furthermore, there is almost universal agreement on them.

Gradation Requirements

The gradation requirement for water-bound macadam is primarily that of a one-size stone, usually 3 1/2 to 1 1/2 or 2 1/2 to 1 1/2 in., and the requirement for the screenings is generally in accordance with the Simplified Practice Recommendations: 100 per cent passing 3/8, 85-100 per cent passing No. 4, and 10-30 per cent passing No. 100.

For graded aggregate base, the gradation requirements generally are stated so that the average of the specifications will give a gradation of maximum density. Studies of the gradations that have been used indicate that the one which gives maximum density approaches Talbot's equation of $P = \left(\frac{d}{D}\right)^n \times 100$, in which the value of n is 1/3 and P is the total per cent passing a given size sieve, d, and D is the maximum size of aggregate.

TABLE I

TYPICAL EXAMPLES OF SPECIFICATIONS FOR GRADED AGGREGATE BASE AND PRACTICAL THEORETICAL GRADATION FOR MAXIMUM DENSITY

Hwy. Dept.	N. C.	Md.	Ohio	Kan.	Kan. Tpk Subbase	Kan. Tpk Base	Theoretical[1] $P = \left(\frac{d}{D}\right)^{1/3} \times 100$
Sieve Size	Total Per Cent Passing						
2 in.	100	100	100	100	100	100	
1½ in.	—	—	—	95–100	75–100	70–100	100
1 in.	75-90	75-95	70-90	—	60-100	60-100	87
¾ in.	—	—	50-85	70-95	—	—	80
½ in.	60-75	60-75	—	—	45-95	—	69
⅜ in.	—	—	—	—	—	39-95	63
No. 4	45-60	45-60	25-60	40-65	25-80	25-75	50
No. 10	—	33-48	—	30-55	17-65	17-55	38
No. 40	15-30	15-30	10-30	16-40	8-40	8-30	22
No. 200	5-20[2]	5-12	5-15	8-20	0-12	0-12	12
L. L.	<25	<25	<30	<30	<30	<25	—
P. I.	<6	<6	<6	2-8	<6	<5	—

[1] P is the total per cent passing a given size sieve, d, and D is the maximum size of aggregate

[2] Actually stated that not less than 5 per cent nor more than 2/3 the percentage passing No. 40

<Not more than

Discussion of Quality and Gradation

While water-bound macadam has received some adverse criticism with regard to ease of construction and riding qualities, there has never been reported a failure of this type of base due to the quality or gradation of the stone used. Probably the reasons for this are that the large size stone is subjected to heavy rolling which causes inferior stone to crush, thereby becoming immediately apparent so that remedial measures might be taken before the job progresses very far. Also, the purpose of the close sizing is to have a uniform distribution of voids, consequently a poor gradation which causes blinding of the surface is immediately seen and can be corrected.

In the graded aggregate base the problems of quality and gradation are not apparent; there has been some trouble reputed to be "softening" and the general requirements as to quality and gradation may be described as being in a state of change. Graded aggregate base material is a mixture of stone and mortar. This mortar is usually described as soil mortar which is defined as a material passing the No. 40 sieve. This soil mortar has been controlled by specifying the liquid limit, plasticity index, and gradation. Most specifications set the liquid limit at not more than 25, the plasticity index at not more than 6, and the gradation is controlled by requiring that not more than 1/3 or 1/2 of the material passing the 40 mesh may pass the No. 200 sieve.

Studies by C. H. McDonald of the Bureau of Public Roads and reported in Highway Research Board Proceedings of 1949, indicate that softening under the action of freezing in the presence of moisture may be caused by the minus 200-mesh material in excess of 10 per cent. Also, most engineers are of the opinion that some binding or setting qualities are desirable, that is, they want some dust or fines, but not too much. Actually it is believed that what engineers desire to achieve in the construction of these base courses is imperviousness. There is divided opinion in the design of base courses under rigid pavements; some think that the base should be drainable while others think that it should be impervious. Specifications generally have divided these two types of bases by requiring not more than 5 per cent shall pass a 200-mesh sieve for a drainable

base, and at least 5 per cent must pass a 200-mesh sieve for an impervious base. One of the advantages of the graded aggregate base is that once the first layer is in place it is impervious and there is no softening of the sub-base or subgrade if a hard rain comes during construction. These considerations have led to some specifications requiring not less than 5 nor more than 12 per cent passing the No. 200 sieve which is quite a narrow range when it is realized that in the past this size fraction has been controlled very little.

Relative Load Transmission

Naturally, in discussing two types of construction, the question arises as to which type is better. The question is impossible to completely answer but there are some indications which merit consideration. The graded aggregate base is not new. It has been built for years, especially in the Mississippi Valley states west of the Mississippi, and has performed well when built of adequate thickness. Water-bound macadam has the longest record of satisfactory performance of any type of base course. Probably the best laboratory evaluation of these two types of bases was made by Raymond C. Herner of the CAA Technical Development and Evaluation Center and reported in the 1955 Proceedings of the Highway Research Board (and the March 1956 issue of the Crushed Stone Journal). Mr. Herner's studies indicated that 17 1/2 in. of dry-bound macadam and 16 in. of graded aggregate possessed essentially the same load transmission values to the subgrade, or more simply stated, possessed the same load supporting properties. Thus, the indications are that for all practical purposes the two types of stone bases are essentially the same as far as supporting loads is concerned.

Crushed Stone Production

In order to give a better concept of the problem of crushed stone production, it may be well to quote a concise statement of the product of a crusher which is: "About 85 per cent of the product of a jaw crusher will pass a screen having openings equal to the jaw setting, about 45 per cent will pass a screen having openings of 1/2 the jaw setting, and about 15 to 25 per cent will pass a 3/16 in. screen for jaw settings above 3/4 in." (Price on Grading of Mineral Aggregates—ASTM Special Technical Publication No. 83)

Most established crushed stone plants have a steady, normal market to supply stone for ready-mixed concrete, bituminous concrete, state maintenance, concrete block, and regular highway paving operations. The bulk of this demand is for 1 1/2 to 1/4 in. sized stone. Water-bound macadam requires about 75 per cent of the stone to be larger than 1 1/2 in. and 25 per cent to be smaller than 1/4 in., so that the demands for this type of construction generally augments production without interfering with the normal markets.

The graded aggregate base construction has flourished in those sections of the country where established crushed stone plants are scarce or non-existent. Material is produced by contractors or companies that specialize in producing stone from approved sources near the project. Generally, the only market for the stone is for the project under construction. Consequently, the lowest cost base stone is that which has the least waste—a graded aggregate that can use all sizes as they are crushed from the maximum size down to and including the dust of fracture. The term "graded aggregate" is used advisedly. It is graded crushed stone with a reasonably uniform distribution of all size fractions and is controlled by rather narrow limits on certain critical sizes. On one job, four crushers were used to make the required gradation. Each crusher was of a different design and capacity.

In this southeastern section of the country as represented by this Association, both types of these crushed stone base courses have been used extensively. Now, we are face to face with a huge road building program which will create a large demand for aggregates. As the quality requirements and gradation control become more restrictive in order to obtain satisfactory performance for the graded aggregate base, the cost of production can be expected to increase and therefore the bid prices can be expected to increase.

Consequently, a condition is being approached where these two types of bases which possess comparable load supporting characteristics could be competitive with one another. In order for the highway department to take advantage of this condition, it would appear desirable to set up designs which offer alternate bids, or for the designing engineer to be well acquainted with the stone production in the area of the project under consideration so that he could specify the type of construction which will offer the greatest economy to the state.

Good Construction Practices

Macadam

First on the list of good construction practices for any flexible base is a well prepared subgrade that is firm and true to grade and cross-section. Upon this subgrade a one to two inch course of screenings should be placed to prevent the intrusion of the soil into the voids of the stone.

The best of construction practices has not found universal application primarily because the small size of many projects has not warranted the purchase of modern equipment. The underlying cause of most of the complaints on water-bound macadam is due to the use of antiquated methods of construction and poor equipment or a lack of modern road-building machines. With modern equipment, macadam base courses are being built to a thickness of 10 in. with the large stone being placed in one layer and the screenings being placed in about three applications. Stone spreaders that can place stone to a stringline grade do a very good job that requires a minimum of evening and hand spotting or filling in of low areas. Once the stone is placed, vibrators do an excellent job of seating or nesting the stone so that rollers then can do their work of compacting thick courses without creeping of the stone. About one-half of the screenings required to fill the voids is spread over the surface and vibrated into place. A second application of screenings is made and vibrated into place. The final application of screenings is made and jarred into the remaining voids by rolling. The last two applications of screenings are of about equal quantity. This procedure provides for placing of the screenings without over-vibrating which causes a separation of the large stone called "jacking." Generally, three passes of a vibrator should be sufficient and final finishing should be done by rolling with a large diameter tandem or three wheel smoothing roller.

Graded Aggregate

The essential requirement in constructing a graded aggregate base is that it must be placed with a minimum of segregation. This objective has been accomplished by two methods of construction: one practiced extensively in the West and the other in the East.

The western practice is about as follows: The graded aggregate is loaded into trucks in a dry condition and weighed. A table of conversion factors which has been established by the engineer gives the number of feet each truck load should cover for the required compacted thickness, which is usually in 4 in. lifts. An inspector marks the distance within which each truck is to dump its load. When two to three thousand feet of road has enough stone for manipulation, a blade grader shapes the aggregate into a windrow of trapezoidal cross-section, and then water is added to bring the moisture content to optimum. The wet aggregate is bladed back and forth across the road until the water is uniformly distributed and there is no segregation. Next, the grader operator will cut out of the windrow enough material for about a 1 in. layer. This layer will be given one or two passes by a multiple tire roller. The process will be repeated until all of the aggregate has been spread, and then it will be rolled until maximum density for the lift has been obtained.

The eastern practice has been to erect a processing plant where the coarse and fine aggregate is proportioned volumetrically and the optimum water is added as the aggregate flows into a continuous pug mill for a thorough mixing of the materials. The mixed material is immediately hauled to the road where it is placed by stone spreaders, often to a loose depth of about 5 in. for a compacted thickness of 4 in.

Either of these two methods prevents segregation and is completely satisfactory. There is no question that segregation is objectionable and no method so far observed has placed dry stone ranging in size from 2 in. to dust without segregation. Mixing with water is an essential part of this type of base construction, whether it is done at a plant prior to delivery on the road or mixed in place is of little moment. It must be mixed with water to prevent segregation and to obtain uniform high density, thereby assuring satisfactory performance.

If these ideas were put into effect, it is believed that with proper specifications and design, good inspection, and competent contractors, the state will get excellent performing stone bases at the lowest cost.

NCSA Makes Changes in Executive Staff

J. R. BOYD BECOMES EXECUTIVE DIRECTOR – J. E. GRAY ENGINEERING DIRECTOR

A. T. Goldbeck Retained as Engineering Consultant

ON August 1, 1956, there became effective several changes within the Executive Staff of the National Crushed Stone Association.

On that date A. T. Goldbeck, who had served the Association so ably as Engineering Director for nearly 31 years, retired to become Engineering Consultant, and J. E. Gray, Field Engineer, was made Engineering Director.

In addition, J. R. Boyd was appointed Executive Director, with the discontinuance of the office of Administrative Director in which capacity he had served the Association for many years.

By training and experience Mr. Gray is exceptionally well qualified to take over the duties of Engineering Director.

J. R. Boyd
Executive Director

J. E. Gray
Engineering Director

He holds from George Washington University the degree of Bachelor of Science in Civil Engineering and the professional Civil Engineering Degree.

His career with the National Crushed Stone Association began in 1928, when he was employed to set up the National Crushed Stone Association Laboratory and to take charge of the research and testing. For 17 years he served the Association in this capacity until in 1945 he was appointed Field Engineer, which afforded him the broad opportunity of putting research results into practice.

While serving as Field Engineer, Mr. Gray developed a wide acquaintance on a professional basis with a great number of testing and materials engineers of the various state highway departments and governmental agencies. Concurrently, through a wide acquaintance with the membership of the National Crushed Stone Association, he has obtained a basic understanding of the production of crushed stone, with particular regard to some of the inherent problems such as gradation, shape, tolerances, and many others. Further, Mr. Gray is well established in the committee work of the engineering societies which are engaged in developing specifications and methods of test for crushed stone.

Mr. Boyd joined the Association Staff in 1925, two weeks following the employment of Mr. Goldbeck. An engineering graduate from George Washington University, he was employed primarily to assist Mr. Goldbeck as Engineering Director and to give such time as was required to the duties of Secretary.

It soon became evident that the administrative work would require his full time, and since shortly after coming to the Association he has served as Administrative Director.

The knowledge and experience gained during nearly 31 years as Administrative Director should prove of great advantage in undertaking his new duties with the Association as Executive Director.

National Crushed Stone Association Safety Competition of 1955

By ELIZABETH K. ELSNER

Under Supervision of Seth T. Reese
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U. S. Bureau of Mines
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ACCORDING to the Bureau of Mines, United States Department of the Interior, the safety record at operations enrolled in the 1955 National Crushed Stone Association Safety Competition was one of the best since this contest was started 30 years ago.

The frequency at which injuries occurred in the 1955 contest—14.445 per million man-hours of work-time—was lower than the rate of 16.923 for the previous year's contest, and it was bettered only in 1939 when a rate of 13.660 was recorded. The severity rate of 2.082 days lost per one thousand man-hours of exposure to the hazards of the industry was next to the lowest such rate attained during the 30-year statistical history of the competition—the lowest rate—1.093 was recorded in the 1945 contest. In addition to these achievements in the 1955 contest, the number of mines and quarries participating was a record high; 30 of the operations worked 2.9 million man-hours without a disabling injury; and the 73 competing plants operated slightly over 7.8 million man-hours—the highest aggregate of worktime since 1949.

Winning Operation

The best record in the 1955 National Crushed Stone Association Safety Competition was made by the Bell underground limestone mine, Bellefonte Division, Warner Company, Bellefonte, Centre County, Pennsylvania. This plant for its outstanding achievement of operating 264,075 man-hours without a disabling injury is awarded a bronze plaque—top honor—provided by the Explosives Engineer Magazine. The award is the second consecutive time this plant has been so honored. In the previous year's contest, because of a disabling injury-free record during a working period totaling 246,689 man-hours, it was similarly honored, and since the plant has been a participant in the contest it was awarded Certificates of Honorable Mention in 1925, 1937, and 1951, because of injury-free records. To all employees at this mine, workers and supervisors alike, such performances were not attained through luck or by chance, but by close team work and cooperation in well planned accident prevention programs. In addition to the trophy a personal certificate is presented to each employee by the National Crushed Stone Association as a tribute to the part he played in achieving the outstanding safety record for his plant in the 1955 Competition.

Bessemer limestone quarry, the Bessemer Limestone and Cement Company, Bessemer, Lawrence County, Pennsylvania, the receiver of top honors in 1943 and 1945, had the next best safety record in the 1955 contest for having a disabling injury-free year during an operating period totaling 229,230 man-hours. In third place, with an injury-free record for 227,587 man-hours, was the Columbia Limestone mine, Columbia Quarry Company, Columbia, St. Clair County, Illinois. The Glen Mills traprock quarry, the General Crushed Stone Company, Glen Mills, Delaware County, Pennsylvania, placed fourth with an injury-free record during 222,987 man-hours of worktime.

Injury-Free Operations

Thirty operations, 22 quarries and 8 underground mines, the latter group including the trophy winner, attained injury-free records in 1955 and are awarded Certificates of Honorable Mention by the National Crushed Stone Association. These 30 plants were worked 2,866,310 man-hours which represented 37 per cent of the total worktime of all 73 competing operations.

These injury-free operations, including the winner, were as follows:

Bell Mine, Warner Company—Bellefonte Division, Bellefonte, Centre County, Pennsylvania; 264,075 man-hours.

TABLE I

RELATIVE STANDING OF QUARRIES IN THE 1955 NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, BASED UPON THE INJURY-SEVERITY RATES OF THE QUARRIES [1]

Rank	Man-hours worked	Number of injuries [2]					Average days of disability per temp. injury	Number of days of disability [2]					Frequency rate [3]	Severity rate [3]
		F.	P.T.	P.P.	Temp.	Total		F.	P.T.	P.P.	Temp.	Total		
2	229,230	—	—	—	—	—	—	—	—	—	—	—	0.000	0.000
4	222,987	—	—	—	—	—	—	—	—	—	—	—	.000	.000
5	187,216	—	—	—	—	—	—	—	—	—	—	—	.000	.000
6	180,140	—	—	—	—	—	—	—	—	—	—	—	.000	.000
7	140,065	—	—	—	—	—	—	—	—	—	—	—	.000	.000
9	116,325	—	—	—	—	—	—	—	—	—	—	—	.000	.000
10	114,800	—	—	—	—	—	—	—	—	—	—	—	.000	.000
11	101,953	—	—	—	—	—	—	—	—	—	—	—	.000	.000
12	94,644	—	—	—	—	—	—	—	—	—	—	—	.000	.000
13	91,159	—	—	—	—	—	—	—	—	—	—	—	.000	.000
15	76,608	—	—	—	—	—	—	—	—	—	—	—	.000	.000
16	69,044	—	—	—	—	—	—	—	—	—	—	—	.000	.000
17	63,924	—	—	—	—	—	—	—	—	—	—	—	.000	.000
18	62,682	—	—	—	—	—	—	—	—	—	—	—	.000	.000
20	60,320	—	—	—	—	—	—	—	—	—	—	—	.000	.000
21	52,201	—	—	—	—	—	—	—	—	—	—	—	.000	.000
22	41,905	—	—	—	—	—	—	—	—	—	—	—	.000	.000
23	37,328	—	—	—	—	—	—	—	—	—	—	—	.000	.000
25	34,176	—	—	—	—	—	—	—	—	—	—	—	.000	.000
26	27,104	—	—	—	—	—	—	—	—	—	—	—	.000	.000
29	16,184	—	—	—	—	—	—	—	—	—	—	—	.000	.000
30	14,403	—	—	—	—	—	—	—	—	—	—	—	.000	.000
32	30,240	—	—	—	1	1	1	—	—	—	1	1	33.069	.033
33	84,576	—	—	—	1	1	4	—	—	—	4	4	11.824	.047
34	136,398	—	—	—	2	2	6	—	—	—	11	11	14.663	.081
35	154,437	—	—	—	1	1	13	—	—	—	13	13	6.475	.084
36	82,211	—	—	—	1	1	8	—	—	—	8	8	12.164	.097
37	102,313	—	—	—	1	1	11	—	—	—	11	11	9.774	.108
38	63,005	—	—	—	2	2	4	—	—	—	8	8	31.744	.127
40	21,984	—	—	—	1	1	5	—	—	—	5	5	45.488	.227
41	36,138	—	—	—	1	1	10	—	—	—	10	10	27.672	.277
42	102,105	—	—	—	4	4	8	—	—	—	32	32	39.175	.313
43	98,520	—	—	—	1	1	35	—	—	—	35	35	10.150	.355
44	192,954	—	—	—	1	1	75	—	—	—	75	75	5.183	.389
45	35,950	—	—	—	1	1	14	—	—	—	14	14	27.816	.389
46	131,974	—	—	—	1	1	55	—	—	—	55	55	7.577	.417
47	140,741	—	—	—	5	5	12	—	—	—	62	62	35.526	.441
48	31,720	—	—	—	3	3	5	—	—	—	15	15	94.578	.473
49	148,500	—	—	—	3	3	25	—	—	—	74	74	20.202	.498
51	228,223	—	—	—	8	8	16	—	—	—	126	126	35.053	.552
52	201,979	—	—	—	4	4	29	—	—	—	117	117	19.804	.579
53	71,508	—	—	—	1	1	44	—	—	—	44	44	13.984	.615
54	78,624	—	—	—	1	1	52	—	—	—	52	52	12.719	.661
55	685,149	—	—	1	9	10	17	—	—	300	154	454	14.595	.663
56	257,770	—	—	—	3	3	62	—	—	—	187	187	11.638	.725
57	46,864	—	—	—	5	5	7	—	—	—	37	37	106.692	.790
58	139,440	—	—	—	5	5	26	—	—	—	129	129	35.858	.925
59	100,656	—	—	—	5	5	20	—	—	—	98	98	49.674	.974
60	89,325	—	—	—	3	3	44	—	—	—	133	133	33.585	1.489
61	114,573	—	—	1	1	2	21	—	—	150	21	171	17.456	1.492
62	153,970	—	—	—	2	2	126	—	—	—	251	251	12.990	1.630
64	33,800	—	—	—	2	2	39	—	—	—	77	77	59.172	2.278
65	26,864	—	—	—	6	6	13	—	—	—	78	78	223.347	2.904
66	52,349	—	—	—	2	2	90	—	—	—	180	180	38.205	3.438
67	70,193	—	—	—	2	2	142	—	—	—	283	283	28.493	4.032
68	64,305	—	—	1	—	1	—	—	—	300	—	300	15.551	4.665
69	55,610	—	—	—	3	3	97	—	—	—	290	290	53.947	5.215
70	63,806	—	—	—	3	3	122	—	—	—	367	367	47.018	5.752
71	22,707	—	—	—	2	2	74	—	—	—	147	147	88.079	6.474
72	321,310	1	—	—	4	5	9	6,000	—	—	37	6,037	15.561	18.789
Totals and rates:														
1955	6,507,189	1	—	3	101	105	32	6,000	—	750	3,241	9,991	16.136	1.535
1954	5,880,228	1	—	9	95	105	24	6,000	—	6,905	2,272	15,177	17.856	2.581

[1] As reports from mining companies are considered confidential by the Bureau of Mines, the identities of the operations to which this table relates are not revealed
[2] F., Fatal; P. T., permanent total disability; P. P., permanent partial disability; Temp., temporary disability
[3] Frequency rate indicates the number of fatal, permanent, and other disabling injuries per million man-hours of exposure; severity rate indicates the number of days of disability lost from injuries per thousand man-hours of exposure

TABLE II

RELATIVE STANDING OF UNDERGROUND MINES IN THE 1955 NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, BASED UPON THE INJURY-SEVERITY RATES OF THE MINES[1]

Rank	Man-hours worked	Number of injuries[2]					Average days of disability per temp. injury	Number of days of disability[2]					Frequency rate[3]	Severity rate[3]
		F.	P.T.	P.P.	Temp.	Total		F.	P.T.	P.P.	Temp.	Total		
1	264,075	—	—	—	—	—	—	—	—	—	—	—	0.000	0.000
3	227,597	—	—	—	—	—	—	—	—	—	—	—	.000	.000
8	120,142	—	—	—	—	—	—	—	—	—	—	—	.000	.000
14	83,439	—	—	—	—	—	—	—	—	—	—	—	.000	.000
19	60,667	—	—	—	—	—	—	—	—	—	—	—	.000	.000
24	36,000	—	—	—	—	—	—	—	—	—	—	—	.000	.000
27	21,914	—	—	—	—	—	—	—	—	—	—	—	.000	.000
28	18,088	—	—	—	—	—	—	—	—	—	—	—	.000	.000
31	60,768	—	—	—	1	1	2	—	—	—	2	2	16.456	.033
39	30,561	—	—	—	2	2	3	—	—	—	5	5	65.443	.164
50	45,653	—	—	—	2	2	13	—	—	—	25	25	43.809	.548
63	154,717	—	—	—	2	2	133	—	—	—	265	265	12.927	1.713
73	192,200	—	1	—	—	1	—	—	6,000	—	—	6,000	5.203	31.217
Totals and rates:														
1955	1,315,811	—	1	—	7	8	42	—	6,000	—	297	6,297	6.080	4.786
1954	915,362	1	—	—	9	10	84	6,000	—	—	754	6,754	10.925	7.379

[1] As reports from mining companies are considered confidential by the Bureau of Mines, the identities of the operations to which this table relates are not revealed
[2] F., fatal; P. T., permanent total disability; P. P., permanent partial disability; Temp., temporary disability
[3] Frequency rate indicates the number of fatal, permanent, and other disabling injuries per million man-hours of exposure; severity rate indicates the number of days of disability lost from injuries per thousand man-hours of exposure

TABLE III

YEARLY SUMMARY—QUARRIES IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, 1926–55[1]

Year	Plants	Man-hours worked	Number of injuries[2]					Number of days of disability[2]					Frequency rate[3]	Severity rate[3]
			F.	P.T.	P.P.	Temp.	Total	F.	P. T.	P.P.	Temp.	Total		
1926	40	5,298,983	3	—	6	207	216	18,000	—	9,000	4,239	31,239	40.763	5.895
1927	48	7,876,791	9	—	2	458	469	54,000	—	2,100	7,186	63,286	59.542	8.034
1928	53	7,509,098	8	—	4	322	334	48,000	—	8,700	5,493	62,193	44.479	8.282
1929	53	7,970,325	4	—	5	286	295	24,000	—	5,760	5,533	35,293	37.012	4.428
1930	68	8,013,415	6	—	9	227	242	36,000	—	7,250	3,671	46,921	30.199	5.855
1931	58	5,085,857	4	—	13	198	215	24,000	—	18,660	3,540	46,200	42.274	9.084
1932	40	2,661,850	1	—	4	75	80	6,000	—	6,750	2,481	15,231	30.054	5.722
1933	40	2,704,871	1	—	1	67	69	6,000	—	48	2,893	8,941	25.510	3.306
1934	46	3,288,257	1	—	2	106	109	6,000	—	2,850	1,873	10,723	33.148	3.261
1935	46	4,166,306	2	1	8	77	88	12,000	6,000	9,900	3,015	30,915	21.122	7.420
1936	50	6,399,023	5	—	14	182	201	30,000	—	8,168	4,590	42,758	31.411	6.682
1937	47	6,199,001	7	—	9	136	152	42,000	—	5,875	4,461	52,336	24.520	8.443
1938	47	4,658,119	2	—	6	76	84	12,000	—	6,600	3,184	21,784	18.033	4.677
1939	44	4,219,086	2	—	2	51	55	12,000	—	4,800	1,678	18,478	13.036	4.380
1940	46	4,358,409	1	—	5	78	84	6,000	—	2,550	3,013	11,563	19.273	2.653
1941	47	5,777,587	3	—	5	98	106	18,000	—	9,300	2,266	29,566	18.347	5.117
1942	48	7,178,935	3	2	1	183	189	18,000	12,000	1,500	4,239	35,739	26.327	4.978
1943	34	4,750,314	4	—	5	134	143	24,000	—	7,146	3,862	35,008	30.103	7.370
1944	32	3,996,433	3	—	4	118	125	18,000	—	3,000	3,323	24,323	31.278	6.086
1945	46	6,087,037	—	—	1	135	136	—	—	750	3,505	4,255	22.343	.699
1946	46	7,292,175	1	—	6	197	204	6,000	—	5,141	4,130	15,271	27.975	2.094
1947	42	6,971,790	5	—	5	197	207	30,000	—	6,900	4,990	41,890	29.691	6.008
1948	47	6,953,569	4	—	11	181	196	24,000	—	8,018	4,642	36,660	28.187	5.272
1949	57	7,166,644	3	—	11	153	167	18,000	—	9,465	3,345	30,810	23.302	4.299
1950	45	6,510,173	2	—	7	153	162	12,000	—	3,854	3,825	19,679	24.884	3.023
1951	36	5,441,304	1	—	4	100	105	6,000	—	6,325	2,381	14,706	19.297	2.703
1952	36	5,279,849	3	—	3	111	117	18,000	—	1,674	2,296	21,970	22.160	4.161
1953	47	6,555,333	—	—	9	114	123	—	—	14,892	2,882	17,774	18.763	2.711
1954	55	5,880,228	1	—	9	95	105	6,000	—	6,905	2,272	15,177	17.856	2.581
1955	60	6,507,189	1	—	3	101	105	6,000	—	750	3,241	9,991	16.136	1.535
Total	—	172,757,951	90	3	174	4,616	4,883	540,000	18,000	184,631	108,049	850,680	28.265	4.924

[1] As reports from mining companies are considered confidential by the Bureau of Mines, the identities of the operations to which this table relates are not revealed
[2] F., fatal; P. T., permanent total disability; P. P., permanent partial disability; Temp., temporary disability
[3] Frequency rate indicates the number of fatal, permanent, and other disabling injuries per million man-hours of exposure; severity rate indicates the number of days of disability lost from injuries per thousand man-hours of exposure

TABLE IV

YEARLY SUMMARY—UNDERGROUND MINES IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, 1926–55 [1]

Year	Plants	Man-hours worked	Number of injuries [2]					Number of days of disability [2]					Frequency rate [3]	Severity rate [3]
			F.	P.T.	P.P.	Temp.	Total	F.	P.T.	P.P.	Temp.	Total		
1926	3	517,926	—	—	—	34	34	—	—	—	533	533	65.646	1.029
1927	2	318,449	1	—	1	14	16	6,000	—	300	68	6,368	50.244	19.997
1928	5	542,193	1	—	1	68	70	6,000	—	300	888	7,188	129.105	13.257
1929	4	665,520	1	—	1	30	32	6,000	—	300	617	6,917	48.083	10.393
1930	6	595,367	1	—	1	15	17	6,000	—	225	468	6,693	28.554	11.242
1931	3	345,105	—	—	—	4	4	—	—	—	147	147	11.591	.426
1932	2	158,450	—	—	—	6	6	—	—	—	165	165	37.867	1.041
1933	3	229,381	—	—	—	11	11	—	—	—	349	349	47.955	1.521
1934	4	248,146	—	—	—	13	13	—	—	—	287	287	52.389	1.157
1935	2	175,994	—	—	—	3	3	—	—	—	249	249	17.046	1.415
1936	4	334,747	1	—	—	7	8	6,000	—	—	117	6,117	23.899	18.274
1937	3	364,680	—	—	—	3	3	—	—	—	91	91	8.226	.250
1938	3	334,442	—	—	—	2	2	—	—	—	133	133	5.980	.398
1939	4	393,039	—	—	1	7	8	—	—	600	457	1,057	20.354	2.689
1940	4	375,987	—	—	1	8	9	—	—	4,500	888	5,388	23.937	14.330
1941	4	591,568	—	—	1	15	16	—	—	750	169	919	27.047	1.553
1942	4	785,894	—	—	1	33	34	—	—	1,800	1,213	3,013	43.263	3.834
1943	5	1,019,771	—	—	3	45	48	—	—	4,950	1,123	6,073	47.069	5.955
1944	4	727,496	1	—	1	27	29	6,000	—	2,400	796	9,196	39.863	12.641
1945	7	1,238,845	—	—	2	22	24	—	—	3,000	755	3,755	19.373	3.031
1946	8	1,338,563	2	—	2	31	35	12,000	—	675	1,045	13,720	26.147	10.250
1947	8	1,291,162	5	—	1	29	35	30,000	—	75	1,588	31,663	27.107	24.523
1948	4	940,031	—	—	—	16	16	—	—	—	935	935	17.021	.995
1949	5	981,692	—	—	1	17	18	—	—	900	467	1,367	18.336	1.392
1950	6	1,102,273	1	—	1	25	27	6,000	—	3,000	810	9,810	24.495	8.900
1951	6	1,179,458	—	—	1	21	22	—	—	1,125	818	1,943	18.653	1.647
1952	6	1,137,449	—	—	—	19	19	—	—	—	583	583	16.704	.513
1953	6	1,260,523	—	—	—	12	12	—	—	—	487	487	9.520	.386
1954	12	915,362	1	—	—	9	10	6,000	—	—	754	6,754	10.925	7.379
1955	13	1,315,811	—	1	—	7	8	—	6,000	—	297	6,297	6.080	4.786
Total	—	21,425,324	15	1	20	553	589	90,000	6,000	24,900	17,297	138,197	27.491	6.450

[1] As reports from mining companies are considered confidential by the Bureau of Mines, the identities of the operations to which this table relates are not revealed
[2] F., fatal; P. T., permanent total disability; P. P., permanent partial disability; Temp., temporary disability
[3] Frequency rate indicates the number of fatal, permanent, and other disabling injuries per million man-hours of exposure; severity rate indicates the number of days of disability lost from injuries per thousand man-hours of exposure

Bessemer Quarry, Bessemer Limestone and Cement Company, Bessemer, Lawrence County, Pennsylvania; 229,230 man-hours.

Quarry No. 3, Columbia Quarry Company, Valmeyer, Monroe County, Illinois; 227,587 man-hours.

Glen Mills Quarry, General Crushed Stone Company, Glen Mills, Delaware County, Pennsylvania; 222,987 man-hours.

Krause Quarry No. 1, Columbia Quarry Company, Columbia, St. Clair County, Illinois; 187,216 man-hours.

Security Quarry, North American Cement Corporation, Hagerstown, Washington County, Maryland; 180,140 man-hours.

Cheektowaga Quarry, Federal Crushed Stone Corporation, Cheektowaga, Erie County, New York; 140,065 man-hours.

Kimballton Mine, Standard Lime & Cement Company, Kimballton, Giles County, Virginia; 120,142 man-hours.

Plant No. 1 Quarry, Callanan Road Improvement Company, South Bethlehem, Albany County, New York; 116,325 man-hours.

White Haven Quarry, General Crushed Stone Company, White Haven, Luzerne County, Pennsylvania; 114,800 man-hours.

Jamestown Quarry, Superior Stone Company, Jamestown, Gilford County, North Carolina; 101,953 man-hours.

Belgrade Quarry, Superior Stone Company, Maysville, Onslow County, North Carolina; 94,644 man-hours.

Ives Quarry, Consumers Company, Racine, Racine County, Wisconsin; 91,159 man-hours.

TABLE V

YEARLY SUMMARY—QUARRIES AND UNDERGROUND MINES IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, 1926–55 [1]

Year	Plants	Man-hours worked	Number of injuries [2] F.	P.T.	P.P.	Temp.	Total	Number of days of disability [2] F.	P.T.	P.P.	Temp.	Total	Frequency rate [3]	Severity rate [3]
1926	43	5,816,909	3	—	6	241	250	18,000	—	9,000	4,772	31,772	42.978	5.462
1927	50	8,195,240	10	—	3	472	485	60,000	—	2,400	7,254	69,654	59.181	8.499
1928	58	8,051,291	9	—	5	390	404	54,000	—	9,000	6,381	69,381	50.178	8.617
1929	57	8,635,845	5	—	6	316	327	30,000	—	6,060	6,150	42,210	37.865	4.888
1930	74	8,608,782	7	—	10	242	259	42,000	—	7,475	4,139	53,614	30.086	6.228
1931	61	5,430,962	4	—	13	202	219	24,000	—	18,660	3,687	46,347	40.324	8.534
1932	42	2,820,300	1	—	4	81	86	6,000	—	6,750	2,646	15,396	30.493	5.459
1933	43	2,934,252	1	—	1	78	80	6,000	—	48	3,242	9,290	27.264	3.166
1934	50	3,536,403	1	—	2	119	122	6,000	—	2,850	2,160	11,010	34.498	3.113
1935	48	4,342,300	2	1	8	80	91	12,000	6,000	9,900	3,264	31,164	20.957	7.177
1936	54	6,733,770	6	—	14	189	209	36,000	—	8,168	4,707	48,875	31.038	7.258
1937	50	6,563,681	7	—	9	139	155	42,000	—	5,875	4,552	52,427	23.615	7.987
1938	50	4,992,561	2	—	6	78	86	12,000	—	6,600	3,317	21,917	17.226	4.390
1939	48	4,612,125	2	—	3	58	63	12,000	—	5,400	2,135	19,535	13.660	4.236
1940	50	4,734,396	1	—	6	86	93	6,000	—	7,050	3,901	16,951	19.643	3.580
1941	51	6,369,155	3	—	6	113	122	18,000	—	10,050	2,435	30,485	19.155	4.786
1942	52	7,964,829	3	2	2	216	223	18,000	12,000	3,300	5,452	38,752	27.998	4.865
1943	39	5,770,085	4	—	8	179	191	24,000	—	12,096	4,985	41,081	33.102	7.120
1944	36	4,723,929	4	—	5	145	154	24,000	—	5,400	4,119	33,519	32.600	7.096
1945	53	7,325,882	—	—	3	157	160	—	—	3,750	4,260	8,010	21.840	1.093
1946	54	8,630,738	3	—	8	228	239	18,000	—	5,816	5,175	28,991	27.692	3.559
1947	50	8,262,952	10	—	6	226	242	60,000	—	6,975	6,578	73,553	29.287	8.902
1948	51	7,893,600	4	—	11	197	212	24,000	—	8,018	5,577	37,595	26.857	4.763
1949	62	8,148,336	3	—	12	170	185	18,000	—	10,365	3,812	32,177	22.704	3.949
1950	51	7,612,446	3	—	8	178	189	18,000	—	6,854	4,635	29,489	24.828	3.874
1951	42	6,620,762	1	—	5	121	127	6,000	—	7,450	3,199	16,649	19.182	2.515
1952	42	6,417,298	3	—	3	130	136	18,000	—	1,674	2,879	22,553	21.193	3.514
1953	53	7,815,856	—	—	9	126	135	—	—	14,892	3,369	18,261	17.273	2.336
1954	67	6,795,590	2	—	9	104	115	12,000	—	6,905	3,026	21,931	16.923	3.227
1955	73	7,823,000	1	1	3	108	113	6,000	6,000	750	3,538	16,288	14.445	2.082
Total	—	194,183,275	105	4	194	5,169	5,472	630,000	24,000	209,531	125,346	988,877	28.180	5.092

[1] As reports from mining companies are considered confidential by the Bureau of Mines, the identities of the operations to which this table relates are not revealed
[2] F., fatal; P. T., permanent total disability; P. P., permanent partial disability; Temp., temporary disability
[3] Frequency rate indicates the number of fatal, permanent, and other disabling injuries per million man-hours of exposure; severity rate indicates the number of days of disability lost from injuries per thousand man-hours of exposure

TABLE VI

NUMBER OF INJURIES, BY CLASSIFICATIONS, AT QUARRIES AND UNDERGROUND MINES IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION IN 1955

Classifications	Fatal	Permanent Total	Permanent Partial	Temporary	Total
Falls and slides of rock or materials	—	—	—	5	5
Handling materials or objects	—	—	—	20	20
Hand tools	—	—	—	5	5
Explosives	—	—	—	1	1
Haulage	—	—	—	11	11
Falls of persons	—	1	—	12	13
Bumping against objects	—	—	—	5	5
Falling objects	—	—	—	15	15
Flying objects	—	—	—	4	4
Electricity	1	—	—	6	7
Drilling	—	—	—	3	3
Machinery	—	—	2	7	9
Stepping on objects	—	—	—	5	5
Other causes	—	—	—	6	6
Total	1	1	2	105	109
Not stated	—	–	1	3	4
Grand total	1	1	3	108	113

TABLE VII

DAYS OF DISABILITY, BY CLASSIFICATIONS, OF INJURIES AT QUARRIES AND UNDERGROUND MINES IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION IN 1955

Classifications	Fatal	Permanent Total	Permanent Partial	Temporary	Total
Falls and slides of rock or materials	—	—	—	35	35
Handling materials or objects	—	—	—	820	820
Hand tools	—	—	—	38	38
Explosives	—	—	—	4	4
Haulage	—	—	—	579	579
Falls of persons	—	6,000	—	294	6,294
Bumping against objects	—	—	—	45	45
Falling objects	—	—	—	368	368
Flying objects	—	—	—	28	28
Electricity	6,000	—	—	506	6,506
Drilling	—	—	—	111	111
Machinery	—	—	450	489	939
Stepping on objects	—	—	—	45	45
Other causes	—	—	—	126	126
Total	6,000	6,000	450	3,488	15,938
Not stated	—	—	300	50	350
Grand total	6,000	6,000	750	3,538	16,288

Bakerton Mine, Standard Lime & Cement Company, Bakerton, Jefferson County, West Virginia; 83,439 man-hours.

Cedar Hollow Quarry, Warner Company, Devault, Chester County, Pennsylvania; 76,608 man-hours.

Martinsburg Quarry, Standard Lime and Cement Company, Martinsburg, Berkeley County, West Virginia; 69,044 man-hours.

Plant No. 1 Quarry, New Haven Trap Rock Company, Wallingford, New Haven County, Connecticut; 63,924 man-hours.

Bakers Quarry, Superior Stone Company, Monroe, Union County, North Carolina; 62,682 man-hours.

Yellow Rock Mine, Kentucky Stone Company, Yellow Rock, Lee County, Kentucky; 60,667 man-hours.

Bonne Terre Quarry, Valley Dolomite Corporation, Bonne Terre, St. Francois County, Missouri; 60,320 man-hours.

Plant No. 4 Quarry, New Haven Trap Rock Company, Plainville, Hartford County, Connecticut; 52,201 man-hours.

Union Furnace Quarry, Warner Company—Bellefonte Division, Tyrone, Blair County, Pennsylvania; 41,905 man-hours.

Prospect Stone Plant No. 6, Eastern Rock Products, Incorporated, Prospect, Oneida County, New York; 37,328 man-hours.

Cape Girardeau Mine, Federal Materials Company, Cape Girardeau, Cape Girardeau County, Missouri; 36,000 man-hours.

Stafford Quarry, Genesee Stone Products Corporation, Stafford, Genesee County, New York; 34,176 man-hours.

Avoca Quarry, Jefferson County Stone Company, Avoca, Jefferson County, Kentucky; 27,104 man-hours.

Boonesboro Mine, Kentucky Stone Company, Richmond, Madison County, Kentucky; 21,914 man-hours.

Mine No. 7, Columbia Quarry Company, Elsberry, Lincoln County, Missouri; 18,088 man-hours.

Randville Quarry, Superior Rock Products Company, Sagola, Dickinson County, Michigan; 16,184 man-hours.

Plant No. 4 Quarry, Southwest Stone Company, Knippa, Uvalde County, Texas; 14,403 man-hours.

Statistics of the Competition

The injury experience at the 73 operations participating in the 1955 National Crushed Stone Association Safety Competition was better than the average for its 30-year history. The injury-severity rate, 2.082 days lost per thousand man-hours of worktime, was 59 per cent lower than the 30-year average severity rate (5.092) and represented the second lowest such rate recorded. In addition, the 1955 severity rate was 35 per cent lower than the corresponding rate of the previous year's contest (3.227). The frequency rate at the competing operations was 14.445 injuries per million man-hours, 49 per cent lower than the contest's 30-year average, and 15 per cent better than the 1954 contest rate (16.923).

Man-hours of worktime or exposure to the hazards of the industry totaled 7,823,000—6,507,189 at the 60 quarries and 1,315,811 at the 13 underground mines. During this volume of work there were 113 disabling injuries of which 1 resulted in death; 1 was a permanent total injury; 3 were partial permanent; and the remaining 108 were temporary total injuries.

Accidents in which handling materials were involved caused 20, or 18 per cent of all injuries for which stated causes were submitted by competing operations; falling objects resulted in 15, or 14 per cent; falls of persons totaled 13 (including 1 permanent total disability), or 12 per cent of the total number of injuries; haulage accidents injured 11, or 10 per cent; and accidents involving machinery resulted in 9, or 8 per cent. The most severe temporary total injuries occurred while materials were being handled; injuries resulting from haulage accidents ranked second; electricity third; machinery fourth, and falling objects fifth. One employee was electrocuted.

Crushed stone operations in 19 states were enrolled in the 1955 competition. New York had 13; Kentucky, 9; North Carolina and Pennsylvania, 7 each; Illinois and Missouri, 5 each; Virginia, 4; Connecticut and West Virginia, 3 each; Maryland, Michigan, New Jersey, Ohio, Tennessee, Texas, and Wis-

TABLE VIII

NUMBER AND PERCENTAGE DISTRIBUTION OF INJURIES AT PLANTS ENROLLED IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION 1953–55, BY CLASSIFICATIONS

Classifications	1953 Number	1953 Per cent of total	1954 Number	1954 Per cent of total	1955 Number	1955 Per cent of total	Total Number	Total Per cent of total
Falls and slides of rock	10	6.8	3	2.9	5	4.6	17	5.0
Handling materials	33	24.8	21	20.2	20	18.3	74	21.4
Hand tools	4	3.0	5	4.8	5	4.6	14	4.0
Explosives	1	.7	—	—	1	.9	2	.6
Haulage	16	12.0	8	7.7	11	10.1	35	10.1
Falls of persons	19	14.3	12	11.5	13	11.9	44	12.7
Bumping against objects	6	4.5	10	9.6	5	4.6	21	6.1
Falling objects	7	5.3	14	13.5	15	13.8	36	10.4
Flying objects	11	8.3	6	5.8	4	3.7	21	6.1
Electricity	2	1.5	1	1.0	7	6.4	10	2.9
Drilling	2	1.5	2	1.9	3	2.7	7	2.0
Machinery	7	5.3	10	9.6	9	8.3	26	7.5
Stepping on object	9	6.8	5	4.8	5	4.6	19	5.5
Burns	2	1.5	4	3.8	—	—	6	1.7
Other causes	5	3.7	3	2.9	6	5.5	14	4.0
Total	133	100.0	104	100.0	109	100.0	346	100.0
Causes not stated	2	—	11	—	4	—	17	—
Grand total	135	—	115	—	113	—	363	—

consin, 2 each; and Georgia, Massachusetts, and Oklahoma, 1 each.

The Competition

The safety competition among operations in the crushed stone industry is conducted by the Bureau of Mines under the same rules as the National Safety Competition. The same records are used in both contests. However, there are two additional requirements that must be established before a crushed stone operation may participate in this competition, namely: (1) It must have commercial production of crushed stone, and (2) It must be a member of the National Crushed Stone Association.

TABLE IX

NUMBER OF AND PERCENTAGE DISTRIBUTION OF DAYS OF DISABILITY FROM INJURIES AT PLANTS ENROLLED IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, 1953–55, BY CLASSIFICATIONS

Classifications	1953 Days of disability	1953 Per cent of total	1954 Days of disability	1954 Per cent of total	1955 Days of disability	1955 Per cent of total	Total Days of disability	Total Per cent of total
Falls and slides of rock	963	5.3	141	0.7	35	0.2	1,139	2.0
Handling materials	659	3.6	488	2.2	820	5.2	1,967	3.5
Hand tools	59	.3	142	.7	38	.2	239	.4
Explosives	1,800	9.9	—	—	4	(1)	1,804	3.2
Haulage	896	4.9	614	2.8	579	3.6	2,089	3.7
Falls of persons	454	2.5	320	1.5	6,294	39.5	7,068	12.7
Bumping against objects	103	.6	357	1.6	45	.3	505	.9
Falling objects	1,683	9.3	6,697	30.8	368	2.3	8,748	15.7
Flying objects	1,975	10.9	3,613	16.6	28	.2	5,616	10.1
Electricity	23	.1	1	(1)	6,506	40.8	6,530	11.7
Drilling	62	.3	97	.5	111	.7	270	.5
Machinery	9,356	51.5	9,129	42.0	939	5.9	19,424	34.8
Stepping on object	51	.3	29	.1	45	.3	125	.2
Burns	15	.1	81	.4	—	—	96	.2
Other causes	67	.4	18	.1	126	.8	211	.4
Total	18,166	100.0	21,727	100.0	15,938	100.0	55,831	100.0
Causes not stated	95	—	204	—	350	—	649	—
Grand total	18,261	—	21,931	—	16,288	—	56,480	—

[1] Less than 0.05 per cent

TABLE X

EMPLOYMENT AND INJURY DATA FOR CRUSHED STONE PLANTS ENROLLED IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION, 1954 AND 1955, COVERING IDENTICAL PLANTS FOR BOTH YEARS AND PLANTS ENROLLED ONLY IN 1954 OR IN 1955 [1]

	No.	Man-hours worked	Number of injuries [2]					Days of disability [2]					Frequency rate [3]	Severity rate [3]
			F.	P.T.	P.P.	Temp.	Total	F.	P.T.	P.P.	Temp.	Total		
Plants enrolled in 1954 only	4	184,907	—	—	2	2	4	—	—	2,250	33	2,283	21.632	12.347
Identical plants enrolled both years, 1954	63	6,610,683	2	—	7	102	111	12,000	—	4,655	2,993	19,648	16.791	2.972
Identical plants enrolled both years, 1955	63	6,656,946	1	1	3	96	101	6,000	6,000	750	3,038	15,788	15.172	2.372
Plants enrolled in 1955 only	10	1,166,054	—	—	—	12	12	—	—	—	500	500	10.291	.429

[1] As reports from mining companies are considered confidential by the Bureau of Mines, the identities of the operations to which this table relates are not revealed
[2] F., fatal; P. T., permanent total disability; P. P., permanent partial disability; Temp., temporary disability
[3] Frequency rate indicates the number of fatal, permanent, and other disabling injuries per million man-hours of exposure; severity rate indicates the number of days of disability lost from injuries per thousand man-hours of exposure

TABLE XI

AVERAGE DAYS OF DISABILITY PER TEMPORARY INJURY AT PLANTS ENROLLED IN THE NATIONAL CRUSHED STONE ASSOCIATION SAFETY COMPETITION

Year	Underground mines			Open quarries			Total		
	Number of temporary injuries	Number of days of disability	Average days of disability	Number of temporary injuries	Number of days of disability	Average days of disability	Number of temporary injuries	Number of days of disability	Average days of disability
1926	34	533	16	207	4,239	20	241	4,772	20
1927	14	68	5	458	7,186	16	472	7,254	15
1928	68	888	13	322	5,493	17	390	6,381	16
1929	30	617	21	286	5,533	19	316	6,150	19
1930	15	468	31	227	3,671	16	242	4,139	17
1931	4	147	37	198	3,540	18	202	3,687	18
1932	6	165	28	75	2,481	33	81	2,646	33
1933	11	349	32	67	2,893	43	78	3,242	42
1934	13	287	22	106	1,873	18	119	2,160	18
1935	3	249	83	77	3,015	39	80	3,264	41
1936	7	117	17	182	4,590	25	189	4,707	25
1937	3	91	30	136	4,461	33	139	4,552	33
1938	2	133	67	76	3,184	42	78	3,317	43
1939	7	457	65	51	1,678	33	58	2,135	37
1940	8	888	111	78	3,013	39	86	3,901	45
1941	15	169	11	98	2,266	23	113	2,435	22
1942	33	1,213	37	183	4,239	23	216	5,452	25
1943	45	1,123	25	134	3,862	29	179	4,985	28
1944	27	796	29	118	3,323	28	145	4,119	28
1945	22	755	34	135	3,505	26	157	4,260	27
1946	31	1,045	34	197	4,130	21	228	5,175	23
1947	29	1,588	55	197	4,990	25	226	6,578	29
1948	16	935	58	181	4,642	26	197	5,577	28
1949	17	467	27	153	3,345	22	170	3,812	22
1950	25	810	32	153	3,825	25	178	4,635	26
1951	21	818	39	100	2,381	24	121	3,199	26
1952	19	583	31	111	2,296	21	130	2,879	22
1953	12	487	41	114	2,882	25	126	3,369	27
1954	9	754	84	95	2,272	24	104	3,026	29
1955	7	297	42	101	3,241	32	108	3,538	33
Total	553	17,297	31	4,616	108,049	23	5,169	125,346	24

Roads Program Moves Forward; BPR Chief Reviews Progress[1]

THE nation's gigantic roads modernization program is moving ahead.

By mid-September—less than three months after the new Federal-Aid Highway Act was signed into law—this was the picture:

New geometric design standards approved by the states and the Bureau of Public Roads for the strategic National System of Interstate and Defense Highways.

Stepped-up activity in 30 states, with 55 road projects under contract and 86 more authorized; total cost estimated at $134 million, of which $106.5 million is the Federal share.

Action Swift

Action has been swift on both BPR and state fronts in carrying out the purposes of the legislation passed by Congress in the last week of June and signed by the President a few days later. The pay-as-you-go legislation set in motion the biggest public works program in the history of the world. The act authorizes federal-aid funds totaling $24.8 billion, to be matched by $2.8 billion by the states, for rebuilding the 41,000-mile Interstate System. In addition, the legislation provides a greatly increased federal-aid program for primary, secondary and urban systems.

Only two weeks after the new highway act was on the books, the American Association of State Highway Officials recommended new Interstate System standards. The standards were submitted to BPR on July 16 and approved the following day.

Commissioner Curtiss Reviews Progress

A comprehensive review of much of the activity under the new highway law was given by C. D. Curtiss, Commissioner of Public Roads, at the 15th annual conference of the Southeastern Association of State Highway Officials.

Mr. Curtiss characterized the standards as "not extraordinarily high." He emphasized they "should not cause misgivings on the part of highway engineers who are trained to design for both adequacy and economy."

"Many states," he said, "are now using on their important roads values above the minimums given in these standards."

The "most important parts" of the standards, the Commissioner declared, "deal with access control and intersections."

The 1956 Federal-Aid Highway Act, in addition to providing road funds, called for extensive studies to be made by the Federal government in cooperation with the states. These studies cover (1) cost of completing the Interstate; (2) maximum desirable sizes and weights of vehicles; (3) reimbursement to the states for Interstate routes built between 1947 and 1957; (4) highway safety, and (5) analysis of cost of providing highway facilities for different classes of vehicles, and benefits derived from highway use by all classes of users.

First Step Accomplished

Mr. Curtiss noted that the first step in study of Interstate System costs was the already-accomplished adoption of geometric standards, and the second step, the location of routes, he said is going rapidly ahead.

Regarding the highway safety study, the Commissioner declared, "It is quite evident that the Congress intends it to be a careful and reasonably deliberate study."

"We expect it to be complementary to the investigation now being conducted by the Roberts Subcommittee of the House of Representatives on the same subject," Mr. Curtiss said, "and we plan to take advantage to the extent possible of the findings of that group in planning our study.

"Two items we plan to include are a pilot study of the real causes of highway accidents and a study of the effect of speed and horsepower on accident causation. In starting this study we are fortunate to have a comprehensive analysis of accident costs nearly completed in Massachusetts and prospects of an early beginning of similar studies in the western region."

[1] Reprint from *Review and Outlook*, September 28, 1956, Automotive Safety Foundation

Basis for Classifying Deleterious Characteristics of Concrete Aggregate Materials*

By E. G. SWENSON† and V. CHALY‡

SYNOPSIS

Deleterious characteristics of concrete aggregate materials are reviewed, and a simplified arrangement for their classification is proposed. This arrangement is based on a recognition of harmful properties rather than on types of materials, thus providing the testing engineer with a more systematic basis for laboratory evaluation of aggregates. Harmful properties that involve chemical action are given the same emphasis as those involving the physical nature of the material. These properties are discussed in relation to the limitations of conventional methods of test and the need for supplementary testing based on petrographic and chemical techniques.

Introduction

THE harmful effect of certain substances in concrete aggregates has been recognized since early times. The Romans specified that sand used for masonry walls "must be fit to mix into mortar and have no dirt in it." Empirical tests have since been developed to detect the presence of undesirable materials, and in recent years the increased application of petrographic and chemical techniques has greatly extended the knowledge of these substances. The list of materials now known to be deleterious in concrete is long but most of the harmful reactions are now understood.

Specifications for concrete aggregates name certain materials as deleterious. They are: coal, lignite, clay, soft fragments, bark, wood, material that passes through the No. 200 sieve, organic matter, and materials harmfully reactive with cement alkali. These substances are taken into account by well standardized methods of testing.

Present specifications, however, distinguish these so-called "deleterious" materials, by inference at least, from other "unsound" materials which are not named. These unsound materials are, in general, related to the parent material, are not easily identified except by petrographic analysis, and may constitute a large proportion of the aggregate. Their presence is determined indirectly by tests such as compressive strength and freeze-thaw tests on mortar and concrete.

This distinction between deleterious materials and unsound materials in aggregate is not altogether tenable. H. S. Sweet[1] has stated that "the subject of deleterious substances is closely allied to the soundness of aggregates and must necessarily be discussed at some length under the latter." C. W. Allen[2] has noted that "the effect of deleterious particles in aggregate overlaps the effect of unsound particles." Since deleterious particles are unsound, and unsound particles are deleterious, no distinction should be made in any general classification.

It is important that the relative nature of the term "deleterious material" be recognized. A certain type of particle may be harmless under one set of exposure conditions, but may be deleterious under other conditions. For instance, certain particles with unfavorable pore characteristics, when incorporated in concrete exposed to frequent cycles of freezing and thawing, break down and rupture the concrete. In more favorable climates, or when the concrete is otherwise protected, such particles may be quite stable. The use to which concrete is put will also determine whether certain substances are to be considered as deleterious. Soft and weak particles in concrete are undesirable where heavy loads must be borne, or where abrasion resistance is required, but they may perform satisfactorily in other cases.

The empirical acceptance tests for aggregates are often inadequate for accurate evaluation. Materials which pass these tests satisfactorily may be unfit for

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use in concrete. W. A. Cordon[3] has reported a case in which a rock easily passed the usual laboratory tests and appeared to be excellent material for aggregate. However, petrographic examination revealed the presence of a considerable amount of interstitial clay which produced excessive expansion in the concrete when the latter was subjected to freezing-thawing and wetting-drying tests.

Conversely an aggregate may fail the usual acceptance tests but may be quite satisfactory in service. In the same report Cordon has cited the case of a sandstone aggregate which failed badly in nearly all laboratory tests but showed good durability to freezing-thawing and wetting-drying tests. Again petrographic examination provided the explanation: the presence of large pores in the aggregate which permitted easy drainage during freezing.

Petrographic and chemical tests have, in many cases, successfully revealed the causes of deterioration of the concrete where other methods have failed. Petrographic methods, in particular, have been developed to permit a more accurate preliminary evaluation of aggregates in the field as well as to explain cases of deterioration of concrete.[4-6] They have become a useful and desirable supplement to conventional acceptance tests but they have required, in use, a detailed knowledge of a wide range of deleterious materials. It is now desirable that such materials be adequately classified, keeping in mind these newer methods of examination, as an aid in systematic evaluation of aggregates.

Bases for Classifying Deleterious Materials

Concrete aggregates, confined to sands, gravels, and quarried rock in this discussion, may be of igneous, sedimentary, or metamorphic origin, each class possessing certain general characteristics as to homogenity, jointing, stratification, and other properties. Within each class there is a wide variation in properties depending on geological processes, chemical and mineralogical composition, degree of crystallization, stratification, and schistosity, chemical activity, and resistance to changes in moisture. For example, a rock may be uniform in composition throughout, or composed of a succession of layers which differ mineralogically; it may be massive or highly stratified; it may be composed of one or several fully crystallized minerals; or it may be microcrystalline or vitrified.

Natural sands and gravels, having gone through the additional processes of transportation and deposition, are subject to greater variations in properties than ledge rock. These processes may have destroyed the weaker particles, thus yielding a harder and more durable material, but they may also have rendered some hard particles unsound.[7]

Both ledge rock and natural sand-gravel aggregate may have been altered because of weathering and aging processes such as freezing-thawing, wetting-drying, heating-cooling, as well as by leaching, oxidation, hydration, and other chemical action.[8] The result is a wide variation in properties of aggregate materials, some of which are undesirable for concrete.

Deleterious materials may be classified according to (a) type of mineral, rock, or other substance; (b) effect on concrete; or (c) characteristics of materials that adversely affect the quality of the concrete. An arrangement based on the type of material would be cumbersome because of the large number of such materials, the complex mineralogical names of many of them, and incompatibility with any simple procedure for testing. A classification based on the effects of deleterious materials on concrete would not be consistent with the testing of aggregates. A simple but comprehensive classification consistent with the methods of testing aggregates for deleterious materials would be one which is based on undesirable properties, or on classes of materials which possess characteristics injurious to concrete. Such an arrangement would provide a proper perspective for the testing engineer and a logical basis for developing a suitable testing sequence. It should be based on both physical and chemical characteristics of aggregates.[8]

F. C. Lang has proposed such a classification.[9] He divides deleterious materials into five classes:

(a) Substances having high volume change, *e.g.*, highly absorptive shales, cherts having high capillarity, and argillaceous limestone

(b) Structurally weak substances, *e.g.*, soft particles with low compressive and flexural strengths

(c) Surface coatings, *e.g.*, dust, clay and encrustations of substances deposited from solution

(d) Shape of particles

(e) Substances affecting chemical activity, *e.g.*, clay, organic materials, sulfides, sugar

Walker and Bloem[10] divide deleterious materials into six categories:

(a) Soft and friable particles which are basically sound
(b) Soft and friable particles which are basically unsound
(c) Hard particles which undergo high volume change
(d) Laminated rocks
(e) Materials which react with certain constituents of cement
(f) Obvious impurities such as coal, lignite, sticks, bark, and mud balls

Neither of these classifications distinguishes between various adverse chemical reactions, nor do they take into account certain harmful physical properties of aggregate particles.

In a recent paper, Mielenz[6] outlines procedures for detailed petrographic examination of aggregates. Evaluation is based on physical and chemical properties of the particles constituting the aggregate, these properties serving as a basis for classification. The term "deleterious," however, appears to be used specifically in relation to chemical reactivity of the aggregate with cement.

Suggested Basis for Classification

A classification of deleterious characteristics of concrete aggregate materials should provide the testing engineer with a background of organized information which will enable him to make an accurate evaluation of aggregates for a job. It should enable him to recognize any limitations of standard specifications and test methods and indicate the need for supplementary tests; it should provide guidance in the selection of a proper sequence of tests; and it should aid in the proper interpretation of test results. So that such a classification can be of immediate value to the testing engineer, it must be comprehensive, but not burdened with highly technical detail and terminology. It should provide general guidance rather than make all the finer distinctions which must necessarily be handled by the specialist.

In the chart and outline in Figure 1 the deleterious characteristics of concrete aggregate materials are divided into two main groups: those which are harmful to concrete due to some physical characteristics, and those involving chemical action. The first class is further subdivided into two groups, those involving external characteristics of aggregate particles, and those concerned with internal properties. The second class, based on chemical action, is subdivided into two groups, one in which chemical action occurs independently of the cement and one where chemical reaction occurs between a cement component and some substance in the aggregate. Some overlapping is unavoidable since some deleterious materials may possess more than one harmful property.

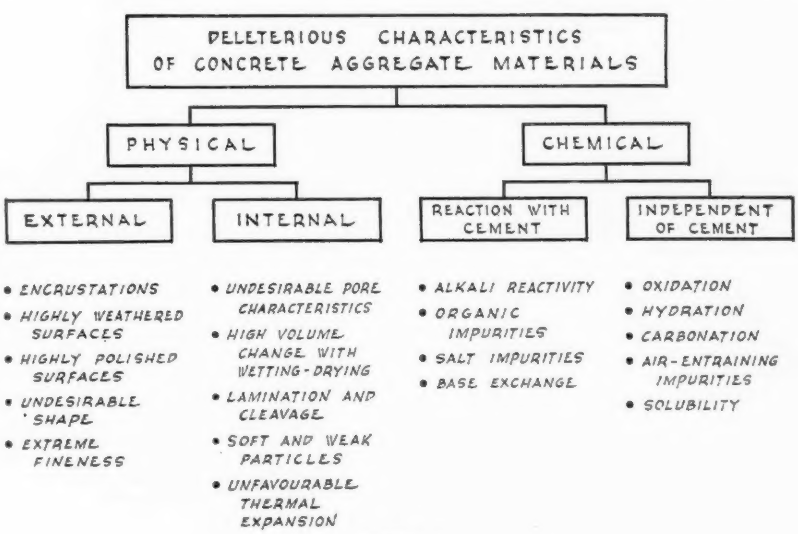

FIGURE 1
Suggested Classification of Deleterious Aggregates

Physical—External

Encrustations—Particles of natural sand, gravel, and larger rock fragments may become coated with a crust of foreign mineral substances. These encrustations may be composed of clay, silt, calcium or iron carbonates, iron oxide, opal, gypsum, or very fine sand cemented by carbonates or oxides through the action of ground waters (Figure 2).

These surface coatings may seriously

FIGURE 2
Coarse Aggregate Particles Coated with Encrustations Precipitated from Ground Waters. Light Portion Largely Calcium Carbonate. Dark Portion Mainly Iron Compounds

weaken the bond between aggregate and cement paste, thereby decreasing the strength and the durability of the concrete. Where flexural strength is an important consideration, such encrustations on aggregate particles are particularly harmful. Encrustations containing reactive materials such as opal may also promote harmful chemical reactions with certain cement constituents. Iron oxide coatings may produce surface stains and may, through hydration, produce excessive volume change in the concrete. Clay and silt coatings tend to increase the quantity of fine material in concrete with possible harmful effects.

In cases where encrustations are strongly bonded to the aggregate particles, the cement-aggregate bonding is not likely to be harmed. A certain amount of coated material can be tolerated in concrete, and the testing engineer must base the allowable limits on the nature of the encrustations and results of tests such as abrasion, soundness, strength, and freezing-thawing.

Surface coatings of this type can be recognized visually or by binocular examination, using an ordinary penknife or needle for detaching loose particles. Identification of the nature of the coated material requires petrographic knowledge.

Highly weathered surfaces—The surfaces of aggregate particles may become altered or decomposed due to weathering processes involving the action of temperature, humidity, frost, soil constituents, and organic materials (Figure 3). These degenerated surface materials may be detached easily from the rock body in which case they are harmful to concrete for the same reason as encrustations. In addition to their poor bonding properties such materials may have high porosity and thereby decrease the durability of the concrete. Where the altered surface crusts are strongly bonded to the rock body, and porosity is not unfavorable, no harmful effects occur.

Altered surface materials may be chemically reactive with cement alkali, and any appreciable amounts of such materials should be tested for this property.

As in the case of encrustations, a limited quantity of such materials can be tolerated but appreciable amounts will adversely affect the concrete, particularly the flexural strength. Aggregate containing considerable quantities of weathered materials will usually fail in standard tests such as abrasion, soundness, strength, and freezing-thawing.

Weathered surfaces can be recognized visually or under the binocular microscope. The degree of weathering can be determined by breaking the particles and observing the depth of the altered material (Figure 4). Petrographic experience is necessary to assess the deleterious nature of the altered material.

Highly polished surfaces—Particles with extremely smooth surfaces may not produce a good

FIGURE 3
Weathered Surface Crusts on Aggregate Particles. Top—Sandstone. Lower Left—Shale. Lower Right—Limestone

bond with the cement paste. If present in high proportion in gravel aggregate they may be considered as deleterious materials, particularly where the flexural strength of the concrete is of major importance. In most cases the detrimental effect of such material is compensated for, in whole or in part, by the lower water requirement of the concrete mix. Comparative strength tests should be made.

Undesirable shape—Slabby or elongated particles, if present in appreciable quantity in aggregate, may seriously affect the strength of concrete, particularly the flexural strength. In addition, such materials accentuate the harshness of a mix and may increase the water requirement to a degree that will affect the quality of the concrete.

Elongated and slabby particles occur mainly from the crushing of quarried rock. Examples are: schists, shales, slates, and other finely stratified sedimentary or metamorphic rocks.

Identification of such materials is simple, but it is important that ledge rock be given preliminary examination to determine its crushing properties.

Highly rounded particles, like highly polished particles, if they constitute a large proportion of the aggregate, may be considered as deleterious due to decreased surface for bonding to the cement paste.

Extreme fineness—Specifications for concrete aggregates limit the quantity of fine materials passing the No. 100 and 200 sieve sizes. Investigations have shown, however, that quantities of clay, for example, considerably in excess of these limits do not affect the quality of concrete adversely.[11]

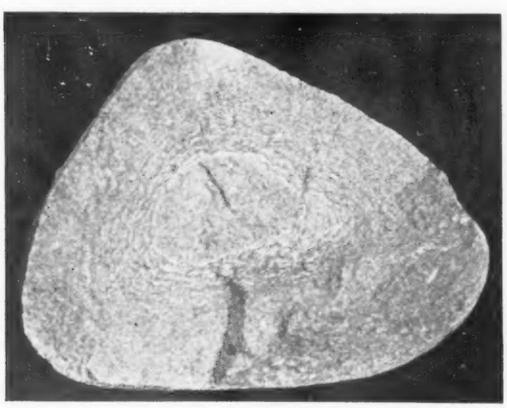

FIGURE 4
Advanced Weathering of Sandstone Showing Small Unaltered Core

The nature of these materials determines the amounts that can be tolerated and investigational tests are required to determine the mineralogical composition and the effect on the strength, volume stability, and durability of concrete.

Physical—Internal

Undesirable pore characteristics—Aggregate particles which possess a combination of high effective porosity and small pore size produce concrete with low durability to freezing and thawing.[7] Interconnected pores or voids of a diameter less than 0.004 to 0.005 mm possess high capillarity but drain effectively only at hydrostatic pressures in excess of the tensile strength of some rocks and concrete. Water is therefore not readily expelled during freezing. Examples are found in all rock types, and often result from alteration due to weathering, leaching, and chemical action.

The relative size of the continuous voids in aggregate particles and in the hydrated cement paste is important to the durability and bond properties of concrete. Large voids in aggregates are drained by the smaller voids in the paste through suction. Smaller voids in the aggregate drain less readily, thereby preventing free passage of water during freezing. This condition may result in rupture at the aggregate-paste interface. Isolated voids, whether large or small, do not appear to have any adverse effect on durability and may actually be beneficial.

Absorption tests give an indication of effective porosity but do not indicate pore size. Absorption values in excess of 2 to 3 percent for 24 hr are considered undesirable but may rule out materials of large pore size which are durable.[1] Two aggregates may yield comparable absorption values, but one may consist of particles of uniform absorption properties and the other may consist of some particles having high absorption and some with low absorption. Absorption tests do not differentiate such cases. It has been found that absorption of aggregate does correlate with freezing and thawing durability of concrete if the material is mineralogically uniform throughout as in the case of limestone. But for lithologically complex aggregates absorption cannot be correlated with soundness.[7]

It has been stated that "the durability of aggregate does not always correlate with the durability of concrete." Magnesium and sodium sulfate soundness tests on aggregate often produce results at vari-

ance with results of freezing-thawing tests on the concrete made with that aggregate. This is due to the different mechanisms involved and to the susceptibility of the soundness test to small variations in temperature, salt concentration, and drying time.

Accelerated freeze-thaw tests are presumed to differentiate between aggregates possessing favorable and unfavorable pore properties. It is generally admitted, however, that such severe tests may reject materials which may be durable under normal weathering conditions. Petrographic analysis is the only certain way of ascertaining the nature of the pore structure of aggregates and of predicting the durability of the concrete in which it is used.

High volume change with wetting and drying—Aggregate particles that expand excessively with wetting produce distress in concrete. Where such particles constitute a large proportion of the aggregate, extensive disintegration may result. If present in small amounts, localized cracking and "popouts" may occur.

Materials possessing this property include laminated particles containing clayey substances, such as clayey limestones and sandstones, cherts, and certain shales. The presence of clay impurities, particularly of the montmorillonite type, makes a rock particle susceptible to high volume change on wetting and drying due to the effect of hydration[8] (Figure 5). Volume change may be different in different directions.

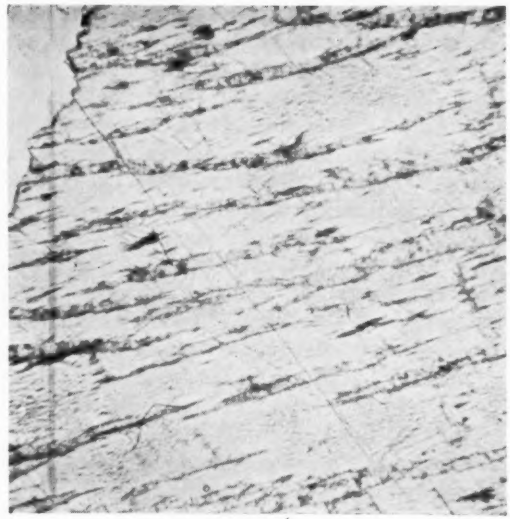

FIGURE 6
Thin Section of Crystal Fragment of Feldspar, Magnified to Show Perfect Cleavage Planes Susceptible to Splitting

Such materials may fail in soundness tests and may show up in freeze-thaw tests in concrete but exceptions have been noted.[3] Wetting and drying tests on concrete are being more widely used to supplement conventional tests. A wetting and drying cycling method has also been developed to detect cement-aggregate reactivity.[12]

Petrographic analyses are important in preliminary examination of aggregate for this property, particularly in the examination of ledge rock to be crushed for use as coarse aggregate.

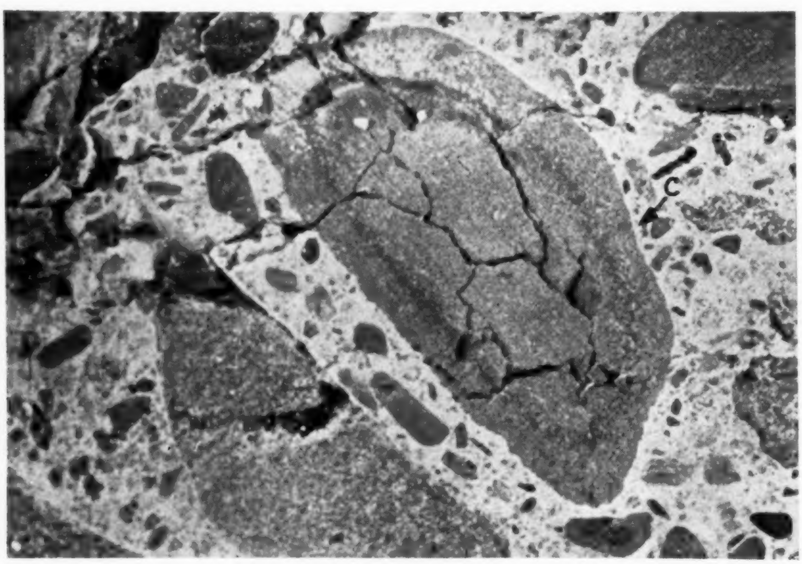

FIGURE 5
Breakdown of Claystone in Concrete Due to Moisture Changes

Lamination and cleavage—Cleavage is the tendency of a crystallized mineral to break in certain defined directions. Some minerals like mica, calcite, topaz, and feldspar possess a perfect cleavage in one or more directions in which adhesion between the two successive mineral lay-

FIGURE 7
Stratified Metamorphic Rock with Pronounced Splitting Following Planes of Weakest Strata

ers is at a minimum (Figure 6). Such monocrystalline aggregate particles may easily split when external stress is applied. A high proportion of such monocrystalline particles in aggregate may affect adversely the compressive and flexural strength of concrete. Monocrystalline fragments of calcite and feldspar, up to 4 in. in diameter and over, are not uncommon.

Stratification and schistosity are also conducive to mechanical splitting due to external stress or to the formation of ice lenses. They occur in schists, shales, slates, and laminated limestones (Figure 7).

Standard tests for aggregates are inadequate for the detection of such materials. Again petrographic examination is of importance in preliminary testing.

Soft and weak particles—Soft and friable particles are structurally weak and possess low resistance to abrasion. In addition they often possess other undesirable properties such as high absorption and high volume change with wetting and drying. A distinction is made between "soft" particles in which the actual grains composing the particles are soft, and "weak" particles in which the grains, either hard or soft, are weakly bonded or interlocked together. For example, some granites are made up of hard crystals of quartz and feldspar in which the grains are poorly interlocked; such materials are "weak" and have low strength, elasticity, and abrasion resistance.

Soft particles with a stable binding material may be basically sound and not subject to excessive volume change with freezing and thawing. Examples are soft sandstones with siliceous or calcareous binder, and certain soft limestones.

Weak particles may be basically unsound due to inherently weak bonding material, and may or may not be subject to high volume change. In this category are many stratified materials such as shales, clayey and limonitic sandstones, also ochres and certain weathered rocks (Figure 8).

Soft and weak particles are detected readily by abrasion, soundness and strength tests, but petrographic examination is valuable for preliminary investigation.

Unfavorable thermal expansion—Aggregate particles that differ greatly from hardened cement paste in coefficients of thermal expansion may seriously affect the durability of concrete subject to large temperature changes.[8] The coefficients for hardened cement paste range from about 5.9 to 9.0×10^{-6}, for concrete from about 3.6 to 6.8×10^{-6}, and for ordinary rocks from about 0.5 to 8.9×10^{-6} per deg F. In spite of these wide ranges any differences in expansivity between aggregate and cement paste have not been shown to be detrimental to the durability of concrete except in the case where the coefficient for the aggregate is below about 1.0×10^{-6} per deg F.[8]

Examples of such materials are found among certain granites, limestones, and marbles.

Many minerals and rock particles show different

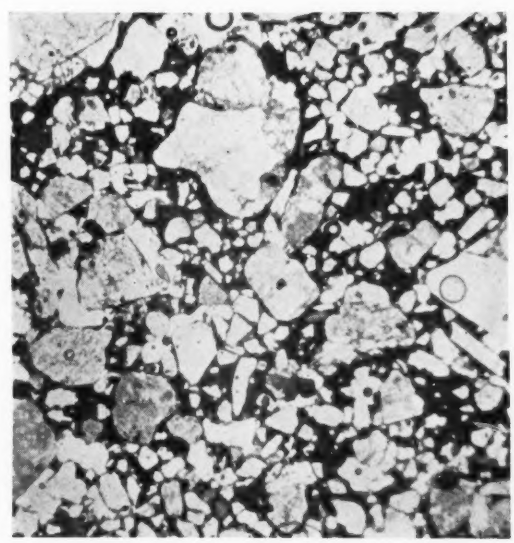

FIGURE 8
Polished Section of a "Weak" Sandstone Composed of Hard Grains (Light) Cemented Together by Weak, Clayey Material (Dark) (x120)

FIGURE 9
Gel Exudations Due to Alkali-Aggregate Reaction, Showing Hardened Gel and Globules of Liquid Gel

thermal coefficients of expansion in different directions, for example, calcite and potash feldspars. Aggregates containing high proportions of particles composed of large crystals of these materials can cause rapid deterioration of concrete subjected to wide and rapid changes in temperature. Large crystals cemented together to form coarse textured rocks may show thermal instability for the same reason.

Identification of such materials can be done effectively by petrographic examination. Their deleterious nature may be revealed by low durability of the concrete to freezing and thawing and heating and cooling. Accelerated freeze-thaw cycling is probably too severe and may cause rejection of materials which are durable under ordinary conditions.

Chemical—Reactivity with cement

It is unfortunate that chemical reactivity in general, and cement-aggregate reactivity in particular, have become associated only with the alkali-aggregate reaction by many concrete engineers. The reaction between cement alkali and certain reactive constituents in some aggregates is only one of several known harmful chemical reactions involving aggregate in concrete.

Alkali reactivity—Certain minerals and rocks react chemically with the alkalies present in cement and produce silicate gels in the concrete (Figures 9 and 10). These gels generate osmotic action in the presence of water which results in the development of hydrostatic pressures within the concrete mass. In extreme cases these pressures may exceed the tensile strength of concrete and produce deterioration (Figure 11).

These reactive materials include minerals such as opal, chalcedony, tridymite and crystobalite; rocks such as glassy or cryptocrystalline rhyolites, dacites, and andesites; also opaline and chalcedonic cherts and phyllites.

Most of these materials appear to be unique in that harmful amounts are limited to a relatively small fraction of the whole aggregate. Aggregates containing large proportions of these materials may produce no harmful effects in concrete. In cases where it is economically necessary to use potentially reactive aggregates, the danger of concrete deterioration may be effectively reduced by using low-alkali cements or by replacing part of the cement with a suitable pozzolanic material.

Potentially reactive aggregates are not revealed by the usual acceptance tests and special methods have been developed. These involve physical, chemical, and petrographic techniques.

FIGURE 10
Hardened Gel Extrusions from Pores on Concrete Surface

FIGURE 11
"Rim" Formation Around Aggregate Particle Due to Alkali-Aggregate Reaction

Organic impurities—The presence of even small amounts of organic materials in concrete will interfere with an effective bond between cement paste and aggregate. Interaction between an organic substance and the cement paste solution may produce secondary substances, such as hydration products, which decrease the strength and durability of the concrete.

Soil humus, wood particles, bark, coal, lignite, and other vegetable and animal products belong in this category. Sand and gravel may become contaminated through carelessness in removal of overburden.

The standard colorimetric test is effective in detecting harmful quantities of organic impurities in aggregate. The presence of coal or lignite may interfere with the proper interpretation of test results, however.

Soluble salt impurities—The presence of soluble salt impurities in aggregate may affect the quality of concrete through salt reaction with a cement component or may affect the setting and hardening by changing the composition of the paste solution.

Possibly the most common salt impurity in aggregate is gypsum. This substance reacts with the aluminate component of the cement, producing a calcium sulfo-aluminate compound with large volume change. The resulting expansion and deterioration of the concrete is similar in nature to that which occurs when ordinary concrete is placed in contact with soils containing high concentrations of soluble sulfates. The rate of setting and hardening of concrete may also be affected.

The usual acceptance tests for aggregates do not reveal the presence of these deleterious substances. Special chemical or petrographic tests are necessary.

Base exchange—Zeolitic minerals and certain adsorptive clays are subject to base exchange in which the calcium ions from the cement paste solution are adsorbed, replacing sodium or potassium ions originally present in these materials. The change in composition of the paste solution may affect the setting and hardening of the concrete. The resulting increase in the alkali content in the paste solution appears to be one cause of excessive efflorescence, and may also promote reaction with alkali-reactive aggregates.

Such deleterious materials can be identified only by petrographic and chemical methods.

Chemical—Independent of cement

Oxidation—Certain minerals, such as iron compounds, may undergo oxidation and produce distress in the concrete through large volume change. Unsightly popouts are often evidence of this reaction (Figure 12). Iron pyrite is an example. Such ma-

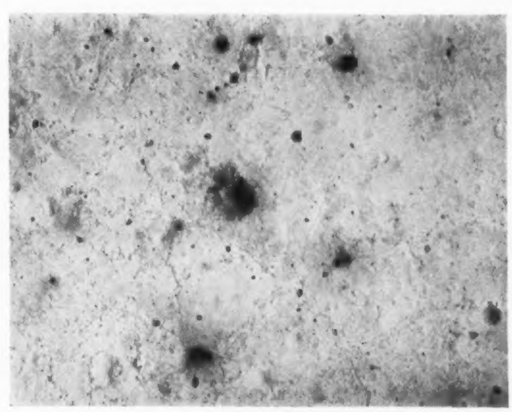

FIGURE 12
"Popouts" in Concrete Due to Oxidation of Iron Compounds in Aggregate

terials are not revealed by the standard acceptance tests and can be identified only by chemical and petrographic methods.

Hydration—Minerals such as pyrites and marcasite may first be oxidized and then hydrated to sulfuric acid and hydrated iron oxides with large increase in volume. Continued oxidation of iron compounds and hydration of iron oxide products in clay ironstones may cause popouts in concrete or extensive deterioration if present in large quantities.

The large volume changes occurring in concrete as a result of wetting and drying are often due to hydration of clayey materials which may be present in the fine fraction of sand or in the strata of laminated rocks in the aggregate.

Standard acceptance tests for aggregate are inadequate for detecting these materials and must be supplemented by petrographic methods of test.

Carbonation—Magnesia impurities in aggregate may become carbonated with a large increase in volume resulting. Such impurities are not easily detectable by the usual tests for aggregates.

Air-entraining impurities—Certain organic impurities which are not revealed by the standard colorimetric test have been shown to entrain large amounts of undesirable air in concrete.[13] This results in a reduction in the unit weight and compressive strength of the concrete and interferes with the function of proper air-entraining agents.

Solubility—Particles which are made up in part of partly soluble compounds such as gypsum may be deleterious to concrete. The soluble constituents may be leached out, leaving a porous particle which is susceptible to freezing and thawing action. Such materials are not detected by the usual tests.

Summary

Present specifications and methods of test for deleterious and unsound materials in aggregate have been subject to considerable criticism.[14] "Instead of trying to enumerate and set limits on the various substances which are considered to be deleterious would it not be better to develop tests based on the particular behavior of these materials which make them injurious to the concrete in which they are embedded?"[9] In this paper an attempt has been made to provide a suitable classification on which suitable tests can be based.

The suggested arrangement gives emphasis to petrographic and chemical concepts which have been largely instrumental in explaining the nature and effects of deleterious materials. It focuses attention on the limitations of conventional acceptance tests and provides a basis for supplementary testing.

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References

1. Sweet, H. S., "Physical and Chemical Tests of Mineral Aggregates and Their Significance," *Symposium on Mineral Aggregates*, ASTM STP No. 83, 1948, pp. 49-73.

2. Allen, C. W., "Influence of Mineral Aggregates on the Strength and Durability of Concrete," *Symposium on Mineral Aggregates*, ASTM STP No. 83, 1948, pp. 152-159.

3. Cordon, W. A., "Selection of Concrete Aggregates," *Lecture* No. 4, U. S. Bureau of Reclamation, Nov. 1948.

4. Mielenz, R. C., "Petrographic Examination of Concrete Aggregates," *Bulletin*, Geological Society of America, V. 57, 1946, p. 309.

5. Mather, K., and Mather, B., "Method of Petrographic Examination of Aggregates for Concrete," *Proceedings*, ASTM, V. 50, 1950, p. 1288.

6. Mielenz, R. C., "Petrographic Examination of Concrete Aggregate," *Proceedings*, ASTM, V. 54, 1954, pp. 1188-1218.

7. Blanks, R. F., "New Concepts in Evaluating and Testing Concrete Aggregates," *Technology of Cement and Concrete*, U. S. Bureau of Reclamation, 1949, 20 pp.

8. Rhoades, R., and Mielenz, R. C., "Petrographic and Mineralogic Characteristics of Aggregates," *Symposium on Mineral Aggregates*, ASTM STP No. 83, 1948, pp. 20-48.

9. Lang, F. C., "Testing for Deleterious Materials in Concrete Aggregates," *Proceedings*, Highway Research Board, V. 18, No. 1, 1938, pp. 250-254.

10. Walker, S., and Bloem, D. L., "The Problem of Deleterious Particles in Aggregates," *Circular* No. 35, National Sand and Gravel Assn., Feb. 1950.

11. Lyse, Inge, "Tests Indicate Effect of Fine Clay in Concrete," *Engineering News-Record*, V. 113, No. 8, Aug. 1934, pp. 233-234.

12. Scholer, C. H., "A Wetting and Drying Test for Predicting Cement-Aggregate Reaction," *Kansas State College Bulletin*, Circular No. 2, Aug. 15, 1950.

13. Macnaughton, M., "A Special Problem of Air Entrainment," *D.B.R. Report* PC 6, National Research Council of Canada, Jan. 1953, pp. 29-33.

14. Woolf, D. O., "Needed Research," *Symposium on Mineral Aggregates*, ASTM STP No. 83, 1948, pp. 221-233.

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Milwaukee 1, Wis.
Symons Cone Crushers, and Symons Gyratory and Impact Crushers; Gyradisc Crushers; Grinding Mills; Stone Plant and Cement Mill Machinery; Vibrating Screens and Grizzlies; Diesel Engines and Diesel Driven Generator Units; Mine Hoists; Track Maintenance Machinery

Northern Blower Co.
6409 Barberton Ave., Cleveland 2, Ohio
Dust Collecting Systems, Fans—Exhaust and Blower

Northwest Engineering Co.
135 South LaSalle St., Chicago 3, Ill.
Shovels, Cranes, Draglines, Pullshovels—Crawler and Truck Mounted

Pennsylvania Crusher Division
Bath Iron Works Corp.
323 South Matlack St., West Chester, Pa.
Single Roll Crushers, Impactors, Reversible Hammermills, Ring Type Granulators, Kue-Ken Jaw Crushers, Kue-Ken Gyratories, Non-Clog and Standard One-Way Hammermills

Pettibone Mulliken Corp.
4710 West Division St., Chicago 51, Ill.
Material Handling Buckets, Clamshells, Draglines, Pullshovels, Dippers, Shovel Dippers, Pumps, Front End Loaders, Bucket Conveyor Loaders, Fork and Bucket Loaders, Speed Swing Loaders, Speed Swing Yard Cranes, Motor Graders, Manganese Steel Castings

Pioneer Engineering Works, Inc.
1515 Central Ave., N.E., Minneapolis 13, Minn.
Jaw Crushers, Roll Crushers (Twin and Tripple), Impact Crushers, Vibrating and Revolving Screens, Feeders (Reciprocating, Apron, and Pioneer Oro Manganese Steel), Belt Conveyors, Idlers, Accessories and Trucks, Portable and Stationary Crushing and Screening Plants, Washing Plants, Mining Equipment, Cement and Lime Equipment, Asphalt Plants, Mixers, Dryers and Pavers

Pit and Quarry Publications, Inc.
431 South Dearborn St., Chicago 5, Ill.
Pit and Quarry, Pit and Quarry Handbook, Pit and Quarry Directory, Concrete Manufacturer, Concrete Industries Yearbook

Productive Equipment Corp.
2926 West Lake St., Chicago 12, Ill.
Vibrating Screens

Quaker Rubber Corp.
Division of H. K. Porter Co., Inc.,
of Pittsburgh
Tacony and Comly Sts., Philadelphia 24, Pa.
Conveyor Belts, Hose, and Packings

Radio Corporation of America
Inspection and Control Section
Front and Cooper Sts., Bldg. 15-1
Camden 2, N. J.
Tramp Metal Detectors

Rock Products and Concrete Products
79 West Monroe St., Chicago 3, Ill.

Rogers Iron Works Co.
11th & Pearl Sts., Joplin, Mo.
Jaw Crushers, Roll Crushers, Hammermills, Vibrating Screens, Revolving Screens and Scrubbers, Apron Feeders, Reciprocating Feeders, Roll Grizzlys, Conveyors, Elevators, Portable and Stationary Crushing and Screening Plants, Mine Hoists, Drill Jumbos and Underground Loaders

Screen Equipment Co., Inc.
1754 Walden Ave., Buffalo 25, N. Y.
Seco Vibrating Screens; Scales—Industrial, Aggregates, Truck

Manufacturers Division – National Crushed Stone Association

(concluded)

Simplicity Engineering Co.
Durand, Mich.
Simplicity Gyrating Screens, Horizontal Screens, Simpli-Flo Screens, Tray Type Screens, Heavy Duty Scalpers, D'Watering Wheels, D'Centegrators, Vibrating Feeders, Vibrating Pan Conveyors, Car Shake-Outs, Woven Wire Screen Cloth, Grizzly Feeders

SKF Industries, Inc.
Front St. and Erie Ave.,
P. O. Box 6731, Philadelphia 32, Pa.
Anti-Friction Bearings—Self-Aligning Ball, Single Row Deep Groove Ball, Angular Contact Ball, Double Row Deep Groove Ball, Spherical Roller, Cylindrical Roller, Ball Thrust, Spherical Roller Thrust; Tapered Roller Bearings; Pillow Block and Flanged Housings—Ball and Roller

Smith Engineering Works
532 East Capitol Drive, Milwaukee 12, Wis.
Gyratory, Gyrasphere, Jaw and Roll Crushers, Vibrating and Rotary Screens, Gravel Washing and Sand Settling Equipment, Elevators and Conveyors, Feeders, Bin Gates, and Portable Crushing and Screening Plants

Stedman Foundry & Machine Co., Inc.
Aurora, Ind.
Stedman Impact-Type Selective Reduction Crushers, 2-Stage Swing Hammer Limestone Pulverizers, Multi-Cage Limestone Pulverizers, Vibrating Screens

Stephens-Adamson Mfg. Co.
Aurora, Ill.
Belt Conveyors, Elevators, Feeders, Car Pullers, Screens, Skip Hoists, Complete Plants

Taylor-Wharton Iron & Steel Co.
High Bridge, N. J.
Manganese and Other Special Alloy Steel and Iron Castings; Dipper Teeth, Fronts and Lips; Crawler Treads; Jaw and Cheek Plates; Mantles and Concaves; Pulverizer Hammers and Liners; Asphalt Mixer Liners and Tips; Manganese Nickel Steel Welding Rod and Plate; Elevator, Conveyor and Dredge Buckets

Thew Shovel Co.
East 28th St. and Fulton Rd., Lorain, Ohio
"Lorain" Power Shovels, Cranes, Draglines, Clamshells, Hoes, Scoop Shovels on Crawlers and Rubber-Tire Mountings. Diesel, Electric, and Gasoline, 3/8 to 2-1/2 Yd. Capacities

Thor Power Tool Co.
175 North State St., Aurora, Ill.
Thor Power Tools, Wagon Drills, Rock Drills, Sump Pumps

Torrington Co.
Bantam Bearings Division
3702 West Sample St., South Bend 21, Ind.
Anti-Friction Bearings; Self-Aligning Spherical, Tapered, Cylindrical, and Needle Roller; Roller Thrust; Ball Bearings

Travel Drill Co.
P. O. Box 1124, Raleigh, N. C.
"Travel Drill"—Mobile Drill for Secondary Drilling in Quarries and Open Pit Work

Traylor Engineering & Mfg. Co.
Allentown, Pa.
Stone Crushing, Gravel, Lime, and Cement Machinery

Trojan Powder Co.
17 North Seventh St., Allentown, Pa.
Explosives and Blasting Supplies

Tyler, W. S., Co.
3615 Superior Ave., N.E., Cleveland 14, Ohio
Woven Wire Screens; Ty-Rock, Tyler-Niagara and Ty-Rocket (Mechanically Vibrated) Screens; Hum-mer Electric Screens; Ro-Tap Testing Sieve Shakers, Tyler Standard Screen Scale Sieves, U. S. Sieve Series

Universal Engineering Corp.
625 C Ave., N.W., Cedar Rapids, Iowa
Jaw Crushers, Roll Crushers, TwinDual Roll Crushers, Hammermills, Impact Breakers, Pulverizers, Bins, Conveyors, Feeders, Screens, Scrubbers. Bulldog Non-Clog Moving Breaker Plate and Stationary Breaker Plate Hammermills, Center Feed Hammermills. A Complete Line of Stationary and Portable Crushing, Screening, Washing, and Loading Equipment for Rock, Gravel, Sand, and Ore. Aglime Plants. Asphalt Plants

Vibration Measurement Engineers
7665 Sheridan Road, Chicago 26, Ill.
Seismographic and Airblast Measurements, Seismological Engineering, Blasting Complaint Investigations, Expert Testimony in Blasting Litigation; Nation-wide Coverage

Werco Steel Co.
2151 East 83rd St., Chicago 17, Ill.
Castings—Manganese, Alloy Steel; Screen Plates—Perforated Steel Screen Sections and Decks; Buckets; Chains; Belt Conveyors, Idlers; Dipper—Shovel; Drop Balls; Wire Cloth; Wire Rope and Related Products

White Motor Co.
842 East 79th St., Cleveland 1, Ohio
On- and Off-Highway Trucks and Tractors—Gasoline- and Diesel-Powered; Industrial Engines, Power Units, Axles, Special Machine Assemblies; All Classes of Service

Wickwire Spencer Steel Division
Colorado Fuel and Iron Corp.
575 Madison Ave., New York 22, N. Y.
Wire Rope, Vibrating and Space Screens

Williams Patent Crusher & Pulverizer Co.
2701-2723 North Broadway, St. Louis 6, Mo.
Hammer Mills, Crushers, Pulverizers, Roller Mills, Reversible Impactors, and Vibrating Screens

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